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Full Length Article

Changes in Growth Parameters of *Moringa oleifera* and Soil Physical Properties in Different Salinity Treatments

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Abstract

The salt tolerance and growth parameters of *Moringa oleifera* Lam. and the improvement of soil permeability by its roots were examined under different salinity treatments (EC_e = 0, 4, 8 and 16 dS/m). The mineral concentrations in the organs of moringa were also investigated. Moringa showed no negative effect of salinity on its growth parameters up to 4 dS/m and those parameters were greatest when moringa was cultivated at 4 dS/m. Negative effects of salinity on the parameters became apparent at 8 dS/m and significant growth inhibition was observed at 16 dS/m. The sodium concentration in each organ increased as the soil salinity increased. The calcium and potassium concentrations in the leaves and the iron concentration in the stems decreased, and the phosphorus concentration in the roots increased with increasing salinity. There were no significant differences in the concentrations of phosphorus, copper, magnesium and zinc regardless of soil salinity or organs. The saturated hydraulic conductivity increased to 10^{-5} m/s at 0 and 4 dS/m and to 10^{-6} m/s at 8 and 16 dS/m compared to 10^{-8} m/s for the soil without moringa cultivation. These findings suggest that growing moringa at 4 dS/m resulted in the greatest growth parameters. The results also indicate that moringa can improve soil permeability through root growth, and therefore, moringa can be grown as a conversion crop in low permeability paddy (*Oryza sativa*) fields to improve soil physical properties under saline conditions. © 2023 Friends Science Publishers

Keywords: Salt tolerance; *Moringa oleifera* Lam.; Soil permeability; Soil salinity; Root

Introduction

Salinization of agricultural land is one of the major environmental problems in not only arid lands but also agricultural lands around the world because of its adverse effects on crop growth. According to FAO (2021a), more than 424 million hectares of topsoil (0–30 cm) and 833 million hectares of subsoil (30–100 cm) are salt-affected. The main causes of salinization in agricultural land are anthropogenic factors such as improper irrigation management in arid and semi-arid regions and natural disasters such as typhoons and tsunamis. In Japan, the tsunami caused extensive salinization of paddy (*Oryza sativa*) fields in coastal areas by seawater at the time of the Great East Japan Earthquake in 2011 (Kume *et al.* 2016). It took more than three years after the earthquake remove salt from 80% of the affected paddy fields in the coastal areas after the earthquake, even if civil engineering works such as topsoil removal and underdrain constructions were conducted in parallel with leaching (Terasaki *et al.* 2015).

To achieve adequate salt removals from the top to the bottom of the soil in the field, it is effective to improve drainages by underdrains and other civil engineering measures, as well as to improve the permeability by plant roots. It is revealed that trees enhance soil permeability (Lorimer and Douglas 1995; Greenwood and Buttle 2014), alder (*Alnus incana*) roots improve soil permeability (Vergani and Graf 2015). However, other studies suggest that effect of trees and roots on soil permeability depends on soil type, soil land use history and vegetation cover type (Lichner *et al*. 2010; Ghimire *et al*. 2014). Different plants have different root structures, which form different pore networks and affect soil permeability differently (Ghestem *et al*. 2011; Archer *et al*. 2013). Thus, to use plants as a development tool of soil physical properties, it is necessary to know the extent to which certain species can influence soil structure and permeability.

This study focused on moringa (*Moringa oleifera* Lam.), which is generally considered to have high salt tolerance and it is considered a "most valuable species" by FAO (2021b) because all parts of the plant, from leaves to roots, can be used and it is rich in nutritional value. Moringa can be used as a fertilizer to increase vitamin C, potassium, calcium, and other minerals in cultivated crops when it is plowed into the soil as a fertilizer (Adekiya *et al*. 2019; Purwito *et al*.,2021).

Salt tolerance of moringa and the effect of salts on root growth have been discussed in many papers. A positive correlation was found between root length and increasing

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salinity while a negative correlation was found between salt stresses and root dry weights (Nouman *et al*. 2012). Root length was only slightly affected by different NaCl concentrations, but no significant difference in dry weight of roots was found among different salinity levels (Elhag and Abdalla 2014). Higher soil salinity significantly decreases growth parameters of moringa such as root surface areas, root projected areas, root volumes and root densities irrespective land races (Farooq *et al*. 2022). Abiotic stress induces a series of morphological disturbances in moringa, resulting in reduced growth (Bekka *et al*. 2022). These findings suggest that moringa can tolerate high salinity and soil physical properties can be improved by its root growth up to a certain value. This study evaluated salt tolerance of moringa, growth parameters and the improvement of the soil permeability by moringa roots under different salinity levels.

Materials and Methods

Cultivation of moringa

The moringa cultivation test was conducted in a greenhouse at the Faculty of Agriculture, Ehime University, Japan. The cultivation period was approximately two months, from August 2 to October 6, 2021. Root boxes (width: 60 cm, height: 40 cm, depth: 10 cm) were prepared for the cultivation test and the soil permeability test. Test soils used in this study were collected from a paddy field in Ehime prefecture, Japan, dried in the sun, and passed through a 2 mm sieve. Soil filling was performed as shown in Table 1, based on data obtained from actual paddy soils. Soil pH and $EC_{1:5}$ were 6.3 and 0.35 dS/m, respectively. The original soil used for this study was non-saline, percentages of Na^+ and Cl^- in the total soluble ions were 0.8 and 2%, respectively. The root boxes were filled with a plow layer and a plowsole to depths of 20 cm and 10 cm, respectively, at the dry densities as shown in Table 1. The plow layer was made of paddy soil only and plowsole was made of a mixture of the paddy soil and gravels (75 and 25% by mass, respectively).

The soils were treated to four salinity levels; one without addition of NaCl (express as 0 dS/m) and three with NaCl added to the plow layer to bring soil salinity to EC_e = 4, 8, and 16 dS/m. The amount of NaCl added was calculated using the conversion method (Gibbs 2000).

Indian moringa seeds were used for the test. Each root box had three compartments resulted in a total of 24 sample trees for four salinity treatments (six plant replications for each salinity treatment). Irrigation was applied as needed and irrigation rate was adjusted daily. The irrigation rate was uniform for all the root boxes, with a small amount of water applied daily until germination and after germination when the soil surface became dry. Fertilizer was not applied during the growing period.

Growth parameters

Growth parameters such as plant height, weight of leaf dry matter, weight of stem dry matter, weight of root dry matter, and weight of total dry matter were recorded following procedures. In the cultivation test, moringa was grown for approximately two months, and the height of the trees was measured immediately after the harvest. The above-ground parts of the plants were harvested, sorted into leaves, branches and stems and oven-dried at 80ºC for 48 h and the dry matter weights were determined. The length of the main roots and the circumference of the thickest part of the main roots were measured after the harvest, and then the dry matter weight of roots was determined.

Mineral concentrations in organs of moringa

The mineral concentrations in each organ of moringa were determined by the following method. First, the furnace-dried samples were ground into a powder for each organ using a vibrating mill. Next, the samples were decomposed using a wet ashing method with nitric acid and perchloric acid. Finally, the mineral concentrations were determined using an ICP-OES (Varian, Vista-MPX).

Soil permeability

The soil permeability was measured after the above-ground parts of the moringa plant was harvested, with the roots remaining in the root box. During the measurements, the temperature was low, and the above-ground portion of the moringa plant had already been harvested, no transpiration and the evaporation from the topsoil was constant and less, and the bottom of the soil was free drainage. After saturating the soil, water was ponded to a depth of 10 cm and the change in water depth and time were recorded. The measured data were substituted into the Darcy's equation to calculate the soil saturated hydraulic conductivity. The average value was obtained from five repeats.

Statistical analysis

ANOVA was performed at the 5% level on the height, dry matters and mineral concentrations of each organ of the moringa cultivated at each salinity treatment. When significant differences were found in the ANOVA, post-hoc tests were conducted using Tukey multiple comparison method at $P < 0.05$ (Haynes 2013).

Results

Growth parameters

The effects of the salinity treatments on the growth parameters are shown in Table 1. The mean height of moringa trees was greatest in the 4 dS/m soil (63.5 cm), followed by 0 dS/m and 8 dS/m (53.5 cm and 52.5 cm, respectively), and was least in the 16 dS/m soil (27.5 cm). The mean heights showed significant difference ($F_{3,20}$ = 3.88, P = 0.02) and the mean height of the trees at 16 dS/m

Table 1: Physical properties of the test soils

Soil	Dry bulk density (g/cm^3)	Particle density (g/cm^3)	Mixing ratio of test soil	
			Paddy soil	Gravel
Plow layer	1.2	2.53	100%	0%
Plowsole	1.7	2.59	75%	25%

Table 2: Effect of salinity on the growth parameters, plant height, weight of dry matters of each organ of moringa trees grown at various salinity levels (PH: Plant height, DM: Dry Matter)

Salinity treatments	PH (cm)	Leaf DM (g)	Branch DM (g)	Stem DM (g)	Root DM (g)	Total DM (g)
0 dS/m	53.5 ± 7.9 ab	2.02 ± 0.35	0.977 ± 0.20	2.47 ± 0.62	9.45 ± 2.2 ab	14.9 ± 2.6 ab
4 dS/m	63.5 ± 7.1 a	2.39 ± 0.49	1.11 ± 0.28	2.96 ± 0.73	10.2 ± 1.4 a	16.7 ± 2.1 b
8 dS/m	52.5 ± 8.5 ab	1.89 ± 0.70	1.03 ± 0.40	2.76 ± 1.2	4.15 ± 0.88 bc	9.78 ± 2.5 a
16 dS/m	27.5 ± 3.9 b	0.812 ± 0.25	0.307 ± 0.12	0.65 ± 0.24	1.42 ± 0.40 c	3.18 ± 0.10 c

Mean ± standard deviation

Table 3: Effect of salinity on soil hydraulic conductivity, root length and root circumference at different salinity levels

Salinity treatment (dS m^{-1})	Soil hydraulic conductivity (m s^{-1})	Root length (cm)	Root circumference (cm)
0	$1.4 \pm 0.38 \times 10^{-5}$	19.3 ± 0.67	13.1 ± 0.88
4	$1.0 \pm 0.10 \times 10^{-5}$	19.7 ± 0.33	13.9 ± 0.94
8	$7.5 \pm 0.28 \times 10^{-6}$	8.7 ± 0.56	9.9 ± 0.66
16	$2.8 \pm 0.17 \times 10^{-6}$	6.3 ± 0.88	6.8 ± 0.48

Mean ± standard deviation

was significantly lower compared to 4 dS/m (Table 2, 3).

The dry matter weight of all crop organs, as well as the tree height, was greatest for moringa grown in the 4 dS/m soil, and moringa in 0 dS/m and 8 dS/m followed and 16 dS/m showed the smallest value. There were no significant differences in the dry matter weight of leaves ($F_{3,20}$ = 0.22, P = 0.88), stems ($F_{3,20}$ = 1.58, P = 0.22) and branches ($F_{3,20}$ = 1.51, P = 0.24) among different salinity levels. The average dry matter weight of the roots was 9.45 g and 10.2 g at 0 dS/m and 4 dS/m, respectively, followed by 8 dS/m at 4.15 g and 16 dS/m at 1.42 g. The root dry matter weight at 16 dS/m was significantly smaller than at 0 dS/m and 4 dS/m ($F_{3,20}$ = 7.68, P = 0.001). The mean total dry matter weight showed a decreasing trend with increasing salinity, in the order of 4 dS/m (16.7 g) > 0 dS/m (14.9 g) > 8 dS/m (9.78 g) > 16 dS/m (3.18 g). The total dry matter weight showed significant difference ($F_{3,20}$ = 4.90, P = 0.01). The total dry matter weight at 16 dS/m was significantly smaller than all other salinity levels and at 8 dS/m was significantly smaller than at 4 dS/m, but there was no significant difference in the values between 0 dS/m and 4 dS/m.

Figs. 1–3 show the results of the correlation analysis of salinity level (soil EC_e) and the plant height (PH), the root dry matter (DM), the total DM, these growth parameters showed significant differences in Table 1. Significant negative correlations were found between soil salinity and these parameters, with correlation coefficients r of -0.85 (P = 0.03), -0.92 (P = 0.009) and -0.94 (P = 0.006) for PH, Root DM and Total DM, respectively.

Mineral ion concentration

Sodium (Na) concentration in each organ of moringa increased with increasing soil salinity. Na concentration in leaves ($F_{3,20}$ = 6.83, P = 0.002), branches ($F_{3,20}$ = 15.4, P = 0.0002), stems ($F_{3,20}$ = 16.9, P = 0.00001), and roots ($F_{3,20}$ = 45.6, $P = 3\times10^{-9}$) were all significantly different among the four different salinity levels (Fig. 4A). Na concentration in each part of moringa did not differ significantly between 0 dS/m and 4 dS/m. Na concentration at 8 dS/m and 16 dS/m was significantly higher than in 0 dS/m and 4 dS/m, indicating a clear trend toward higher Na concentration at higher salinity levels. Especially in roots, Na concentration of 8 dS/m was significantly different from 0 dS/m and 4 dS/m, and 16 dS/m value was significantly different from all other values.

Other than Na, significant differences were observed for potassium (K) ($F_{3,20}$ = 7.90, P = 0.001) (Fig. 4B) and calcium (Ca) ($F_{3,20}$ = 4.19, P = 0.02) (Fig. 4C) in the leaves and iron (Fe) ($F_{3,20}$ = 7.69, P = 0.001) in the stems (Fig. 4D) among four different salinity levels. These mineral concentrations decreased with increasing salinity. No significant differences in the concentration of phosphorus (P) (Fig. 4E), magnesium (Mg) (Fig. 4F), copper (Cu) (Fig. 4G), and zinc (Zn) (Fig. 4H) were observed with increasing soil salinity at all organs. As soil salinity increased, Na concentration of leaves tended to increase while K concentration decreased.

Soil permeability

The hydraulic conductivity of uncultivated soil (1.1×10^{-8} m/s) was improved by more than two orders of magnitude by the moringa cultivation. Mean saturated hydraulic conductivity was greatest in 0 dS/m soil (1.4×10^{-5} m/s), followed by 4 and 8 dS/m (1.0×10^{-5} and 7.5×10^{-6} m/s, respectively) and was the least in 16 dS/m soil (2.8×10^{-6} m/s). Root length shortened but its circumference decreased

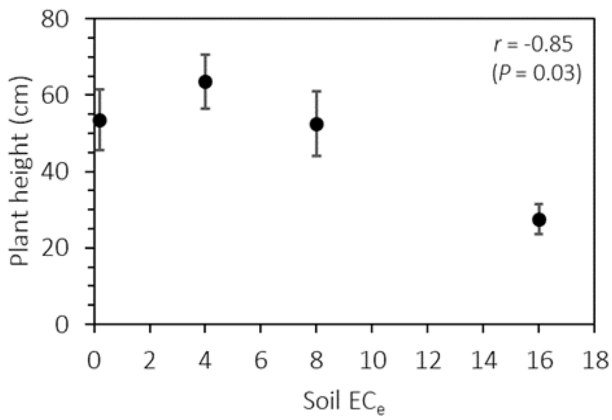

Fig. 1: Relationship between soil EC_e and plant height

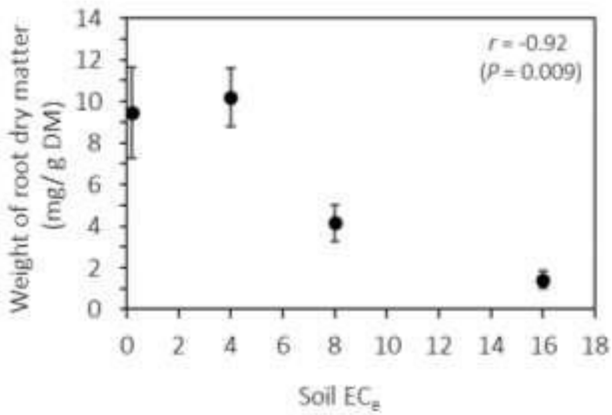

Fig. 2: Relationship between soil EC_e and weight of root dry matter (DM)

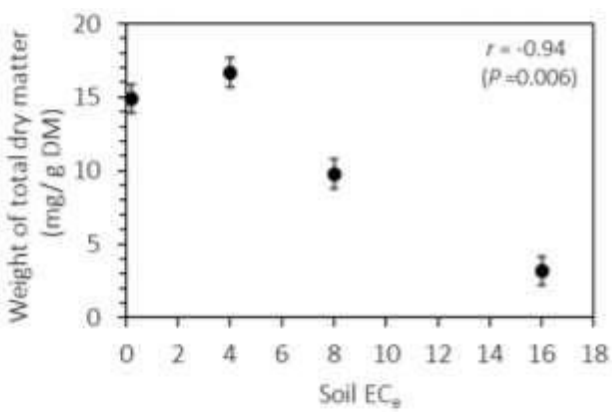

Fig. 3: Relationship between soil EC_e and weight of total dry matter (DM)

with increased soil salinity. Length and circumference of root at 16 dS/m were 30 and 50% at 0 dS/m, respectively. Positive correlations were found between saturated hydraulic conductivity and root length (r = 0.88, P = 0.02), root circumference (r = 0.96, P = 0.02) in both cases.

Discussion

It is well known that yields begin to decline at 4 dS/m in many crops (ASCE 1996). In this study, the growth of moringa in the 4 dS/m NaCl-supplemented soil was similar to or better than that in the 0 dS/m soil without NaCl for each growth parameter. Plant improves water use efficiency under salt and drought treatments, and *Pnicum antidotale* demonstrated the positive role of Na and Cl in carbon assimilation and osmotic adjustment with drought treatments (Hussain *et al*. 2020). Moringa, a salt-tolerant crop, had a similar function, suggesting that slight to moderate salinity stress had a positive effect on growth parameters.

Nouman *et al*. (2012) used acid-washed sand, which is different from the soil properties of this study but showed that moringa was able to survive under 8 dS/m with little reduction in nutrient values. Farooq *et al*. (2022) concluded that germination rates, root surface areas, and above-ground growth were largely unaffected at up to 3.5 dS/m based on the results of a study using four *Moringa oleifera* landrace species. Elhag and Abdalla (2014) found that moringa is salt tolerant up to 8 dS/m in tests with alkaline heavy clay, with significantly lower values for heights and the leaf dry weight at 16 dS/m (30% reduction in heights, 40% reduction in leaves, respectively). The results of moringa growth in this study using CL (clay loam) soils with weak acidity (pH = 6.3) showed that salinity had little effect on growth up to 4 dS/m, the effect became apparent at 8 dS/m and the significant growth inhibition at 16 dS/m. These results are consistent with the results of previous studies using different soils, indicating that the moringa growth is not significantly affected by soil properties and responds to salinity stress in a similar manner.

Na concentration in plants increases with increasing salinity not only in moringa but also in barley (*Hordeum vulgare*) (Flowers and Hjibagheri 2001) and other herbaceous plants (Hussain *et al*. 2020). Similar to the previous studies, this study also showed that Na concentration increased with increasing salinity in all organs of moringa. Concentrations of Ca and K in leaves and Fe in stems decreased with increasing salinity. Ca and K in leaves decreased with increasing Na concentration in moringa (Elhag and Abdalla 2014). In triticale (*Triticosecale*) and barley, an increase in Na has been found to decrease K (Karim *et al*. 1993; Flowers and Hjibagheri 2001). The decrease in K with increasing Na concentration was also observed in paddy and other crops (Naidoo *et al*. 2007). In this study, a significant positive correlation was found between Na and P at the root in this study (r = 0.63, P = 0.001), Elhag and Abdalla (2014) and Nouman *et al*. (2012) obtained the same results. The results of this study suggest that moringa roots may have functioned to promote growth by increasing the absorption of P in response to increased Na. There were no significant differences in the concentrations of Cu, Mg, and Zn regardless of soil salinity

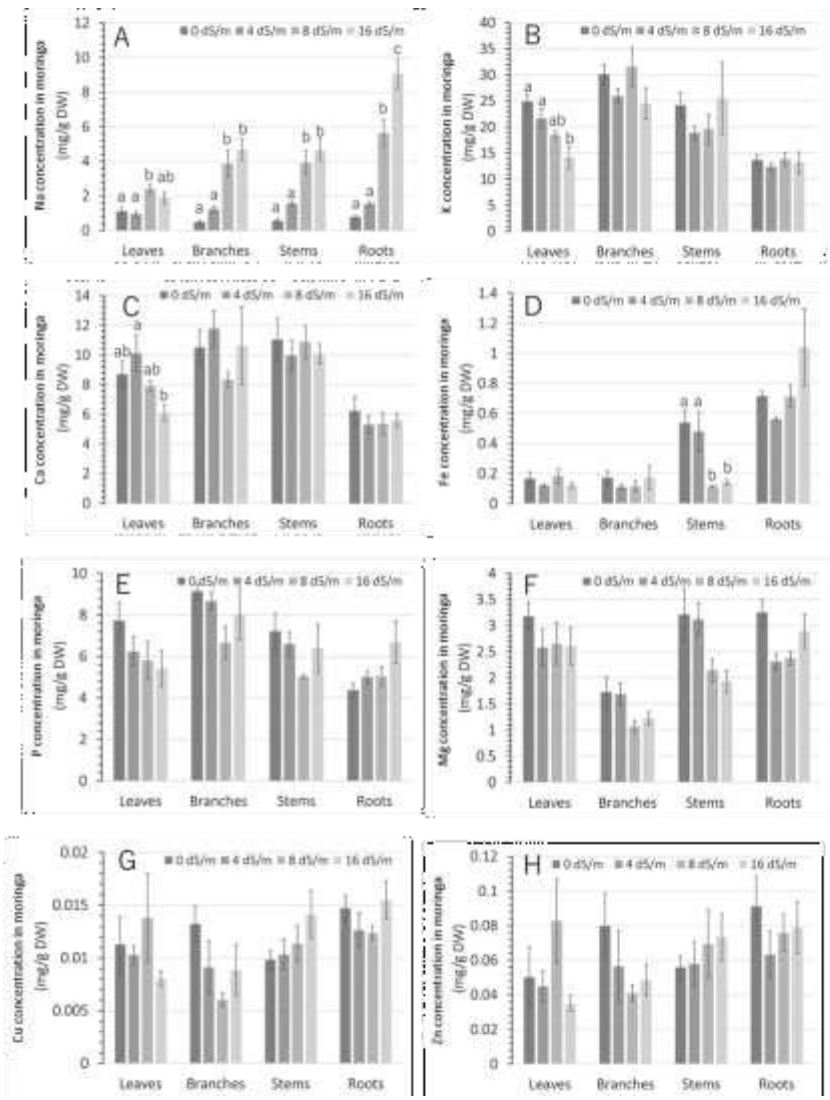

Fig. 4: Mean values of mineral concentrations (**A**: sodium (Na), **B**: potassium (K), **C**: calcium (Ca), **D**: iron (Fe), **E**: phosphorus (P), **F**: magnesium (Mg), **G**: copper (Cu), **H**: zinc (Zn)) in each organ of moringa grown at various salinity levels (Error bars indicate standard error and different letters indicate significant difference at $P < 0.05$)

or organ. Matsumaru (1993) analyzed concentrations of mineral concentrations in eight horticultural crops in various parts of the crop. The results showed that Na concentration was higher in roots and lower in stems and leaves, indicating organ-specific differences. In addition, K and Ca decrease in leaves and roots, respectively, as Na increases, and the same results were obtained for roots in this study. Matsumaru (1990) found no clear relationship between Fe, Mn, and Zn concentrations and increasing salinity in cucumber (*Cucumis sativus*) plants based on the results of salt tolerance tests. These results suggest that moringa is unlikely to inhibit the absorption of these mineral concentrations even when soil salinity increases.

The saturated hydraulic conductivity in the test soils decreased with increasing salinity, *i.e.*, with decreasing the root dry matter weight. The root dry matter weight in moringa was positively correlated with the length and the circumference of the main root. *Sophora japonica*, with its tap tree roots, has the effect of loosening deeper soils with deeper and more vertical roots, greatly increasing soil infiltration rates (Zhang *et al*. 2019). Vergani and Graf (2015) stated that A*lunus incana* roots improved soil permeability after 2 months of growth. The saturated hydraulic conductivity was shown to be one order of magnitude greater in the 0 dS/m and 4 dS/m soils than in the 8 dS/m and 16 dS/m soils, and two orders of magnitude greater than in the soils not cultivated with moringa.

Conclusion

Growing moringa at 4 dS/m resulted in the greatest growth parameters, so growing moringa at slight to moderate saline

conditions under 4 dS/m is recommended to maximize the yields. Moringa showed almost the same response to salinity in various types of soil, suggesting that salinity can be used to estimate the degree of growth without considering the physical properties of the soil. The results indicate that moringa can improve soil permeability through root growth, and therefore, moringa can be grown as a conversion crop in low permeable paddy fields to improve soil physical properties.

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Author Contributions

Kume and Shimamura planned experiments and conducted the data analysis. All authors discussed details of results and discaussion part.

Conflicts of Interest

All authors declare no conflicts of interest.

Data Availability

Data presented in this study will be available on a fair request to the corresponding author.

Ethics Approval

Not applicable in this paper.

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